# Growth response in a Douglas-fir/lodgepole pine stand after thinning of lodgepole pine by the mountain pine beetle: A case study

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## ABSTRACT
Diameter growth response was measured in a mixed stand of lodgepole pine, *Pinus contorta* Dougl. ex Loud, and interior Douglas-fir, *Pseudotsuga menziesii* var *glauca* (Beissn.) Franco, in the Cariboo Forest Region of British Columbia, 14 years after an outbreak of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, killed 76% of the pine. Nearly all Douglas-fir and a large proportion of the lodgepole pine responded to the beetle-induced thinning with a diameter growth increase which persisted 14 years after the infestation. Douglas-fir trees gained an average 1.4 cm or 11.7% in diameter over the estimated size the trees would have reached in the absence of the thinning effect. Annual growth rates of Douglas-fir in the post-outbreak period averaged 2% per year without the beetle-induced thinning and 2.9% after thinning. The surviving lodgepole pine trees gained an average 1 cm or 5.4% in diameter over the size the trees would have reached in the absence of the thinning effect. In the post-outbreak period, annual diameter growth rates of the pine doubled from 0.4% per year without the thinning, to 0.8% per year with thinning. The thinning response in Douglas-fir was inversely related to the initial diameter and age of the trees at the start of the infestation but that of pine was not.

## INTRODUCTION
Mixed stands of lodgepole pine, *Pinus contorta* Dougl. ex Loud, and interior Douglas-fir, *Pseudotsuga menziesii* var glauca (Beissn.) Franco, are typical of large areas of the Cariboo Forest Region of British Columbia (B.C.). Throughout this region, the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, kills mature and overmature lodgepole pine in extensive infestations that last for several years (Safranyik *et al.* 1974). A series of outbreaks in many stands in the east-central area of the Region occurred during the 1970–80 period. For example, an outbreak which began on the Chilcotin Plateau in 1971/72 continued unabated until 1985, killing approximately 22,000,000 $m^3$ of pine over 1,700,000 ha (Doidge, personal communication) before collapsing after two extremely cold winters in 1985/86. Most infestations collapsed prior to the depletion of a highly susceptible host. In mixed stands, because of a selective killing of lodgepole pine, a thinning or release effect, manifested as an acceleration of the trees' growth rates, was expected to occur among the Douglas-fir and the surviving lodgepole pine. Such a release was demonstrated by Cole and Amman (1980) who detected growth acceleration in lodgepole pine after each of several beetle infestations. Because the beetles tend to kill mainly the large diameter lodgepole pine trees in a stand (Craighead 1925, Cole and Amman 1969, Safranyik *et al.* 1974), the type of thinning that the beetles cause correspond to a thinning from above (Smith 1962).

Information on the growth response of interior Douglas-fir and lodgepole pine to thinning is relatively scanty. Knutson and Tinning (1986) studied the response to thinning of young Douglas-fir with varying degrees of infection by dwarf mistletoe and concluded that trees with no or low infection responded to thinning with a significant increase in radial growth, while severely infected trees did not. Studying a lodgepole pine stand in Alberta, which underwent a combination of thinning from above and below, Johnstone (1982) demonstrated that semi-mature (77-year-old) lodgepole pine responded well to thinning. Waring and Pitman (1985) concluded that 120-year-old lodgepole pine responded to thinning and fertilization with increased growth efficiency and vigor, which in turn decreased the risk of beetle-caused tree mortality.

This paper quantifies the diameter growth response in a mixed Douglas-fir–lodgepole pine forest 14 years after the start of a mountain pine beetle infestation, which over a number of years, selectively killed a large proportion of the pine.

## MATERIALS AND METHODS

The studies were conducted in an area known as Bull Mtn., about 4 km north of Williams Lake, B.C. (Latitude 52°15′, Longitude 122°7′) in the Cariboo Forest Region. The area studied occupied about 65 ha, was located at an elevation of approximately 970 m, on relatively flat terrain ($\leq$ 8% slope) and included the B.C. Forest Service forest types PL631 and F841. The stands are in the IDFdk3 biogeoclimatic subzone (Ray Coupé, pers. comm.) and growing on a medium quality site (Ordell Steen, pers. comm.). The site potential is rated as relatively good for the Cariboo Forest Region. The forest cover consisted of a two-storied mixture of Douglas-fir and lodgepole pine with a minor component of white spruce, *Picea glauca* (Moench) Voss. An outbreak of the mountain pine beetle started in the Bull Mtn. area in 1971 and lasted until 1975 when the epidemic completely collapsed (Doidge 1974, 1975). At the end of the infestation, many but not all lodgepole pines had been killed. By 1985 the average age of the Douglas-fir component was 63 years; surviving lodgepole pine averaged 107 years. The understory, defined as trees which are less in height than the average lowest live branches of the overstory (approximately 7 m), was well stocked and primarily Douglas-fir.

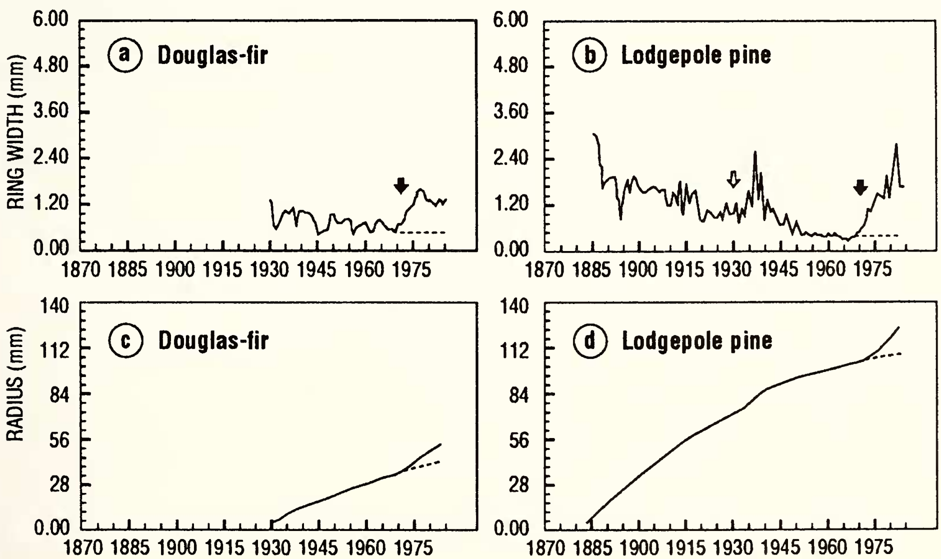


Fig. 1. Radial increment (a,b) and cumulative radial growth curve (c,d) from one surviving Douglas-fir and one lodgepole pine tree from the Bull Mountain area of British Columbia, showing the growth increase that occurred after the mountain pine beetle selectively killed a large proportion of the lodgepole pine starting in 1971. The dotted line corresponds to a projection of the growth trend (by linear regression) of the 20 years before 1971. The solid arrow points to the year 1971, the year in which the outbreak began. The open arrow indicates the start of an earlier release period, around 1930, possibly caused by a previous mountain pine beetle epidemic.

Two surveys of the area were conducted by the B.C. Min. of Forests and Lands, Cariboo Region. The first, in 1975, consisted of 98 pairs of concentric circular plots on a 50 × 50 m grid. One of the plots in the pair was 0.008 ha in area and was intended to measure overstory conditions; the second was 0.002 ha in size and was used to collect data on the regeneration (File Report by R. Gasson, August 1976, on file at the Cariboo Regional Office). The second survey was conducted in the fall of 1985, and consisted of 49 pairs of concentric circular plots on a 100 × 100 m grid. In this case, the plot sizes at each point were 0.01 ha and 0.005 ha for the overstory and understory plots, respectively. The objective of both surveys was to establish the amount and condition (alive or dead) of the overstory and understory. For every overstory tree, diameter at breast height (DBH) was measured. Growth rates after the beetle outbreak were determined in 1985 through collection of one breast-height increment core in each overstory plot from a live dominant or co-dominant Douglas-fir (i.e., a total of 49 Douglas-fir cores collected). Cores were also collected from 20 living dominant and co-dominant lodgepole pine randomly selected throughout the stand.

Thinning response was measured by comparing the actual diameter of the cored trees as of 1985 with a theoretical diameter the trees would have reached by this date in the absence of the beetle outbreak. The theoretical diameter was calculated as follows. Annual ring increments were measured on the cores to the nearest 0.01 mm using a DIGIMIC tree ring measuring device (Holmann Electronics, Fredericton, N.B., Canada) and the software developed by Alfaro *et al.* (1984). Every ring increment series was plotted *versus* date of ring formation and crossdated (Stokes and Smiley 1968). A linear regression curve was then fitted to the ring increments grown in the 20 years preceding the initiation of the outbreak in 1971 (Fig. 1). By projection of this linear regression, theoretical increments without thinning were calculated for every year between 1972 and 1985. In a few cases where the linear regression method gave poor projections (e.g., projected increments dipped below the X-axis), the projection was discarded and theoretical increments for the 1972-1985 period were assumed equal to the average growth of the 5 years that preceded 1972. Theoretical radii and diameters were determined by accumulation of the tree ring series but using the theoretical increments for the 1972–1985 period. The actual and theoretical diameters are respectively referred to hereafter as the thinned and unthinned tree diameter.

For both Douglas-fir and lodgepole pine, mean diameter and basal area gain per tree due to thinning was calculated as the difference between the thinned and unthinned tree diameter. In addition, a study was done of the relationship between diameter and basal area gain per tree *versus* tree diameter and age at the start of the infestation (1971). The percentage annual growth of thinned and unthinned trees for the period between 1971 and 1985 was calculated using the compound interest formula (Husch *et al.* 1972).

To confirm that any increase in growth rate during the post-outbreak years was due to a thinning effect and not to a coincident period of abnormally favourable weather, increment cores were randomly collected from a 20 additional lodgepole pine trees of similar age and size to those on Bull Mtn., but from a stand which had not undergone a beetle outbreak. The stand selected was located near Lyne Creek, about 10 km northwest of the Bull Mtn. study site, and was approximately 100 years old in 1985 (age range 83–112). It was located in the same biogeoclimatic subzone, had similar stocking levels, and was also growing on a medium site (Steen, pers. comm.). Annual ring widths in these cores were measured and graphed *versus* dates, with the same instruments and methods used for the Bull Mtn. cores.

## RESULTS AND DISCUSSION

Although no direct data are available on the stand structure before the beetle epidemics at this location, an approximation was obtained by adding the figures for the number of beetle-killed and live trees reported in 1975. Before the beetle outbreak, the overstory contained approximately 560 living stems/ha, consisting of 80% lodgepole pine, 19% Douglas-fir and 1% white spruce. In 1985, 14 years after the start of the beetle epidemic, the stand contained 430 living stems/ha, with the pine component reduced to 20% and the Douglas-fir and white spruce increased to 77% and 3%, respectively. These changes in stand structure were due to the high mortality of the pine induced by the beetle and to the acceleration of Douglas-fir growth which resulted in understory trees being recruited into the overstory. Seventy-six percent of the pine stems/ha were dead (81% by basal area) which represented 38% of the total stems/ha in the stand (43% by basal area).

In 1975, the understory contained an average 3190 trees/ha composed of 90% Douglas-fir and 5% each of lodgepole pine and white spruce. In 1985, the understory contained 2698 trees/ha with a similar composition; 91% Douglas-fir, 7% lodgepole pine and 2% white spruce.

**Thinning response of Douglas-fir**

All but one of the 49 Douglas-fir trees cored showed a marked increase in radial growth in the period that followed the beetle outbreak, relative to the trend line fitted to the growth prior to the start of the infestation in 1971 (Fig. 1). The increase began 1 to 4 years from the start of the infestation, and reached a maximum 5 to 7 years after. By 1985, many trees still had growth rates above the trend line. However, considerable tree-to-tree variation occurred which was probably due to spatial and temporal differences in pine mortality, to a relatively heterogeneous stand structure and to variations in the sample trees' crown size and position in the crown canopy.

Average DBHib (DBH inside bark) of Douglas-fir in 1985 was 13.4 cm (range 8.3–24.6). The 1985 DBHib in the absence of the thinning effect, was estimated at 12.0 cm (7.2–23.6). Hence, the average diameter gain due to the beetle-induced thinning was 1.4 cm (0–4.4), which amounted to an average increase of 11.7% (0–57%) over the size of the unthinned tree (average increase of 21% by basal area).

Regression analysis indicated that the thinning response (as measured by the difference in DBH with and without thinning) was lower in the large diameter and older trees than in small diameter and younger trees ($F = 6.0$ and $F = 5.9$, for the diameter and age relationships, respectively; both significant at $P < 0.05$). However, there was considerable variation in the response, particularly among trees of small diameter or of young age. The regression line explained only about 10% of the variance. Inclusion of the number or percentage of lodgepole pine trees killed in each plot in the analysis did not improve the regression.

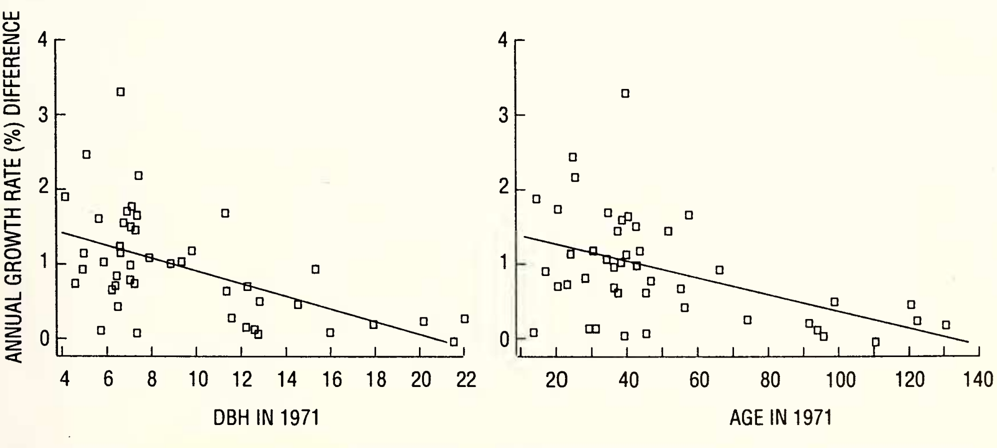


Fig. 2. Difference between thinned and unthinned annual growth rates (%) of Douglas-fir *versus* initial DBH (cm) and tree age (years) in 1971. Thinning was the result of a mountain pine beetle outbreak, which killed a large proportion of the lodgepole pine.

Based on the 1971 and 1985 diameters, and using the compound interest formula, thinned and unthinned annual growth rates averaged 2.9% (0.2–6.5%) and 2% (0.1–5.7%) per year, respectively. In terms of basal area, the average annual growth rate was 6% (0.3–13.5%) per year with thinning, and 4% (0.2–11.7%) per year without thinning. The difference between thinned and unthinned annual growth rates is shown in Fig. 2. Again, these figures show larger percentage growth gains among the small diameter trees of young age relative to larger or older trees. Trees with diameters greater than 21 cm or older than 140 years showed no response. For the same age or diameter, there was a large tree to tree variation in the thinning response (Fig. 2).

**Thinning response of surviving lodgepole pine**

Fourteen out of the 19 lodgepole pine sampled showed a similar growth acceleration period after the start of the beetle outbreak of 1971 to that in Douglas-fir. The increase started 2–6 years from the start of the outbreak and peaked 5–9 years after; growth still remained above the trend line as of 1985.

Average 1985 DBHib for lodgepole pine was 19.5 cm (range 12.6–26.5 cm). The 1985 mean unthinned diameter was estimated at 18.5 cm (12.7–25.0 cm). Hence, the average diameter gain due to thinning (including the trees that did not show a response), over the 14 year post-outbreak period was 1.0 cm which was equivalent to a 5.4% increase over the size of the unthinned tree (12.3% by basal area). In lodgepole pine the degree of response to thinning was not significantly related ($P > 0.05$) to the diameter or age of the trees at the start of the infestation.

The percentage annual diameter growth rates for the 14 year period ending in 1985, doubled from 0.4% per year (0.1–0.7%) without thinning to 0.8% per year (0.1–1.7%) with thinning. Annual basal area growth rates averaged 1.7 and 0.8% per year with and without thinning, respectively.

Examination of the plots of annual ring increment for lodgepole pine at Bull Mtn. indicated an earlier release period starting about 1930 (Fig. 1), probably caused by an earlier beetle infestation. The Douglas-fir in the stand was younger than the lodgepole pine and originated about that date, possibly by seeding into the openings created by the bark beetle.

**Growth in the Lyne Creek area**

Increment cores of lodgepole pine from Lyne Creek did not show the increase in diameter growth after 1971 seen at Bull Mtn. On the contrary, tree rings from this area showed the normal pattern of decline with age and growth in the 1972–1985 period was, on average, 17% less than growth in the previous 10 years. Since the two locations are exposed to similar climatic conditions, it was concluded that the release at Bull Mtn. was due to the beetle-induced thinning.

## DISCUSSION

The mountain pine beetle caused a drastic change in the stand structure in this area as the overstory changed from largely lodgepole pine, a shade intolerant species, to predominantly Douglas-fir, a more tolerant species. Removal of the mature pine, a seral species on this site, increased the rate of successional change towards a Douglas-fir dominated stand. The same pattern of change does not occur in much of the Chilcotin where lodgepole pine is a pyraledaphic climax species and no shade-tolerant conifer species are available to replace beetle-killed pine. Stands in the IDFdk3 biogeoclimatic subzone with significant Douglas-fir or white spruce components can withstand heavy pine mortality levels and still become commercially viable in a reasonable period. Overstory Douglas-fir stocking densities on Bull Mtn. increased from 106 stems/ha (19% of the stand) in 1975 to 331 stems/ha (77% of the stand) in 1985 with an average inside bark diameter of 13.4 cm. The diameter growth response of the Douglas-fir and residual lodgepole pine will help produce a commercially viable stand on the site within 15–20 years (assuming an economic threshold mean outside bark DBH of 25–30 cm). The shift to a higher value species like Douglas-fir will have an additional economic impact on the stand.

Several bark beetle researchers have indicated that vigorous growth increases tree resistance to bark beetle attack and shortens outbreak duration (Brown *et al.* 1987, Cole and Amman 1969, Nebeker and Hodges 1983, Vité and Wood 1961, Waring and Pitman 1985). Before the bark beetle outbreak, lodgepole pine growth rates were near stagnation and the large proportion of the lodgepole pine that showed release response in this study could have been a factor in the termination of the outbreak in the area, along with a depletion of the most attractive host.

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